Modelling radiation-induced cellular damage: nuclear models and data needed for radiation protection and hadrontherapy

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Tumour treatment with protons and Carbon ions is now performed by an increasing number of facilities since it can allow for a better optimisation of Tumour Control Probability and Normal Tissue Complication Probability, particularly for radioresistant tumours. Moreover, protons and heavier ions are of concern in particular radiation protection scenarios such as exposure to space radiation. Nuclear interactions with the beam line components (for hadrontherapy), the spacecraft walls (for space radiation protection) and the human body can significantly modify the radiation field.

The FLUKA transport code, integrated with radiobiological data and coupled to anthropomorphic phantoms, is applied to the characterisation of therapeutic proton beams and the calculation of space radiation organ doses. Besides absorbed doses, quantities more directly related to biological damage (often referred to as "biological doses") can be calculated. In this work the "biological dose" is modelled as the yield of "complex lesions", which are clustered DNA breaks.Very good agreement was found with experimental data obtained at the OPTIS proton therapy facility. The relative contribution of nuclear reaction products was higher for the "biological dose" than for the absorbed dose, mainly due to the higher biological effectiveness of target fragments. The effects of Galactic Cosmic Rays and Solar Particle Events were simulated as a function of the shield thickness. Again, the nuclear reaction products provided a larger relative contribution to the "biological dose" than to the absorbed dose. While SPE doses decreased by increasing the shield thickness, GCR doses showed more complicated trends due to the higher complexity of the radiation spectrum.

Since Complex Lesions can evolve into chromosome aberrations (which are correlated with cell death and oncogenic transformation), a model and code simulating aberration induction was developed, also in view of an interface to FLUKA. The model predicts dose-response curves for the main aberration categories induced in human cells by different radiation types, both as monochromatic and as mixed fields. The very good agreement with data provided a validation of the model, confirming the fundamental role of energy deposition clustering at the nanometer and micrometer levels.

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